Original scientific paper

Comparison of Cable Skidding Productivity and Cost: Pre-Choking Mainline Versus Tagline Systems

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Abstract

This study quantifies the operational efficiency and cost of pre-choking main and tagline systems for tree-length extraction using a cable skidder. The study was done by comparing productivity and costs of the two systems in a semi-mechanised tree-length harvesting operation. Study data was collected using time studies and work sampling for choking and dechoking operations, and GNSS tracking for recording and analysing machine in-field travel time and skidding distance. Operating costs were estimated using South African Harvesting and Transport Costing Model. Average productivity of the tagline system (46 m^3 PMH^{-1}) exceeded that of the mainline system (34 m^3 PMH^{-1}) by 35%. The extraction cost of the tagline system (US\$1.10 m^{-3}) was 26% lower than the cost of using the mainline system (US\$1.50 m^{-3}).

Keywords: cable skidding, mainline system, tagline system, productivity, cost, extraction, time study

1. Introduction

One of the most common methods of primary transportation (extraction) for pine sawlog production in South Africa is ground-based cable skidding (Ackerman et al. 2014). Ground-based primary transport from stump to roadside landing (i.e. extraction) of tree-lengths or tree sections using specialised primary transport equipment, such as an articulated skidder, is impacted by the terrain conditions normally encountered. These include slope, low bearing capacity soils and surface obstacles such as rocks, depressions, stumps and felling debris (Kluenderet al. 1997, FESA 1999). Grapple and cable skidder are the two types of articulated skidders most commonly used. At present cable skidders are more prevalent than grapple skidders in South Africa (Ackerman et al. 2014). They are mostly used in larger timber as their productivity is severely compromised when extracting smaller dimension trees or tree parts (de Wet 2000). As the name suggests, a cable skidder uses a winch to draw the trees to the machine and then skid them to a roadside landing. Globally, cable skidding is the only method currently being used post motor-manual felling since stems are often scattered throughout the compartment, making this method of extraction necessary for the efficient gathering of logs (Rummer 2002). Further, skidding is also required for extraction in difficult and steep terrain (Bejhou et al. 2008). Cable skidders use either mainline or tagline systems (i.e. the winching method attaches chokers to a mainline or taglines) to gather and draw trees or tree sections to the machine, although tagline systems are not common in South African extraction systems.

The choking system, most often used in South Africa, is the mainline system, utilizing a single set of choker chains or cable chokers. This system is less productive compared to pre-choking, which uses two (or even three) sets of chain or cable chokers, or a tagline choking system (Bromley 1969, APA 1988, De La Borde 1992, MacDonald 1999). The mainline system comprises a wire rope that forms the main line to which the individual tree-lengths are attached by shorter wire ropes or chain chokers (Fig. 1). The mainline wire rope, typically used in South African operations, is a 19 mm diameter IWRC wire rope (depending on tree-size) that is 50 m or longer in length and fitted with 4–6 sliders (which slide on the main-line). Each slider can accommodate a choker attached to a tree-length

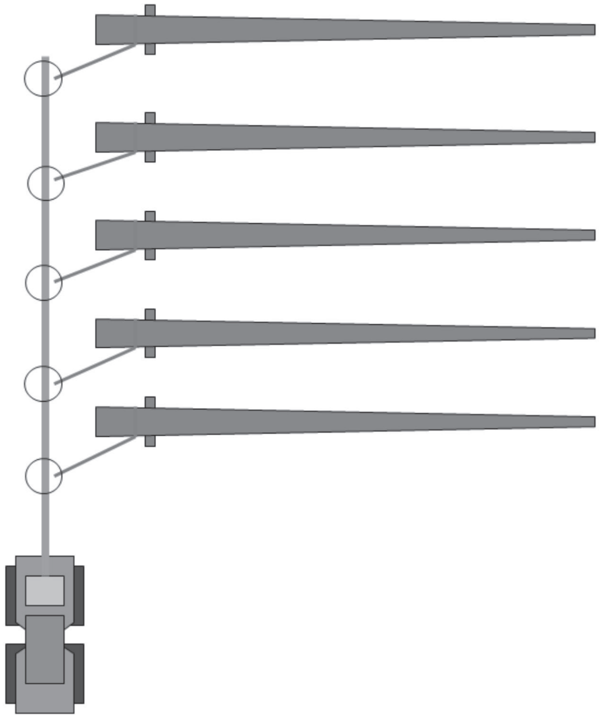

Fig. 1 Diagram of mainline rigging system: the main line is a wire rope to which tree-lengths are attached by shorter wire ropes or chain chokers

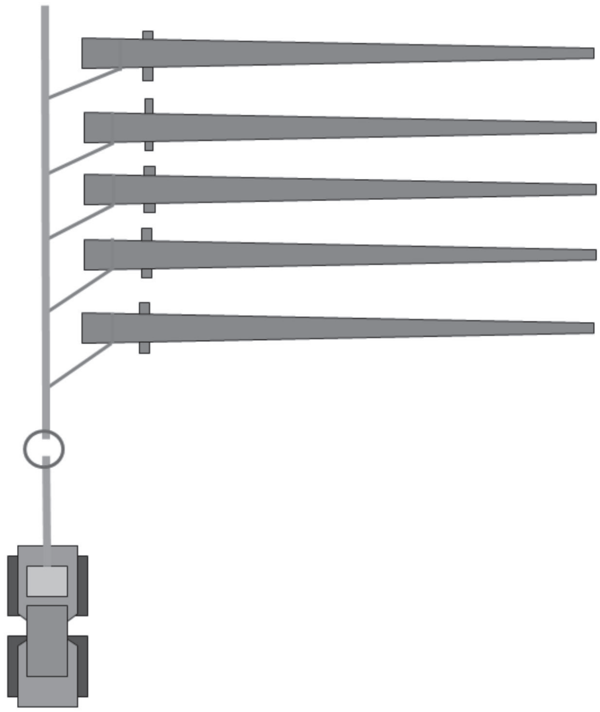

Fig. 2 Diagram of tagline rigging component: sliders are set up along the tagline similarly to the mainline system, but the end of each tagline is fitted with a hook for easy attachment when winching

or tree section. The number of sliders fitted to the mainline depends on the skidder power, tree size, wire rope diameter and terrain.

Choker chains are mainly used in South Africa. They are made of a 1.8 to 2.0 m length of 10 mm or 12 mm diameter Herc-Alloy chain (depending on the application) with rings or hooks at one end, which are set around either the thin or butt end of a tree-length or tree section. During load hook-up, the winch brake is released and the mainline is pulled from the winch drum to individual or bunched tree-lengths identified for the next extraction cycle. The tree-lengths are then attached to the mainline by slotting the chain ends into the sliders mentioned above. They are then winched to the skidder and skidded to the roadside landing. At the landing, a choker setter releases the load from the choker. The mainline, along with the chokers, are winched back to the skidder to be returned to the field for the next cycle (APA 1988).

The use of two sets of choker chains allows pre-choking and can significantly increase productivity of operations by reducing the terminal cycle times. Pre-choking involves choker setters setting the load using one set of choker chains infield while the skidder extracts the previous load to the roadside landing. The skidder returns infield with the chokers that have just been off-loaded, and the set already pre-choked is attached to the mainline for the next cycle. The result of this is that the skidder spends less time waiting to pick up the load compared to when a single set of choker chains is used (APA 1988).

The tagline choking system, commonly making use of two sets of chain chokers, has been reported to be more productive than the mainline system (Bromley 1969, APA 1988, De La Borde 1992, MacDonald 1999). The tagline system of extraction involves the use of a tagline to assemble tree sections for extraction (Fig. 2). A tagline is approximately 15 to 20 m in length and of the same dimension as the mainline. The setup of sliders is exactly the same as the mainline system outlined above. The end of each tagline is fitted with a hook or a loggerhead grab for easy attachment to the mainline before winching. Three taglines are used in the operation as follows: at any one time, one tagline is infield being pre-choked, the second is travelling loaded with the skidder to the landing, and the third is being de-choked at the landing after which it is returned infield (De La Borde 1992).

When the skidder returns infield, the empty tagline is off-loaded and the mainline pulled from the winch drum to the loaded tagline. The loaded tagline is attached to the winch mainline and winched back to the skidder for extraction to the roadside landing. At the roadside, a choker setter unhooks the mainline from the load once it has dropped to the ground and attaches the empty tagline (from the previous load) to return infield (Bromley 1969, De La Borde 1992). This tagline system significantly minimises the waiting times both at the roadside landing and infield (de Wet 2000, Lusso 2003).

The objective of this study was to compare the efficiency of a mainline system with two sets of choker chains to a tagline choking system with three sets of choker chains in terms of productivity (m^3 PMH^{-1}) and cost (US\$ m^{-3}). Productivity in terms of Productive Machine Hours (m^3 PMH^{-1}) and cost (US\$ m^{-3}) of pre-choking in a mainline system with two sets of choker chains was compared to a tagline system with three sets of choker chains.

2. Materials and Methods

The study was conducted on three *Pinus radiata* compartments harvested by Cape Pine Investment Holdings Ltd. located near the town of Grabouw in the Western Cape Province of South Africa. The stand and site conditions for each compartment are shown in Table 1. The terrain conditions provided in Table 1 are based on the classification system by Erasmus (1994). Compartments M7a and M7b were adjacent to each other but separated by a stream. Their terrain conditions were similar, as well as stand conditions, having been established at the same time and subjected to the same silvicultural treatments as shown in the compartment records.

Time study, work sampling and Global Navigation Satellite System (GNSS) tracking were used to obtain information about each system. Time study was done using stop watches to record time consumption for choker-setting and dechoking. Work sampling was used to systematically and critically examine the methods applied in executing the various tasks, thus providing detailed time-based information on each work element. GNSS tracking, due to its ability to perform autonomous time studies, monitor and track mobile machines (Spruce et al. 1993, McDonald 1999, Reutebuch et al. 1999, Veal et al. 2000, Veal et al. 2001, Robert 2002, Ronald et al. 2006), was used to gather complimentary data to the time study and work sampling. Travel times and speeds were also extracted from the GNSS data. The GNSS system comprised of a GPS device (FM LOC GPS) was installed on the skidder to record operational data, which was then analysed using FDO Fleet Manager Professional Version 8.3 software. Through GNSS tracking, detailed summaries of machine system performance over long periods of time alongside spatial detail of machine travel including distances, speeds and travel times could be recorded and matched with time study data. Choking time, dechoking time, travel loaded and travel empty data were combined into a work cycle and used in calculating productivity per productive machine hour (PMH).

The three compartments were each divided into three strips. Each of the strips had two predetermined designated skid trails located parallel to each other 30 m apart (Fig. 3). The position of each skid trail was marked and cleared of trees and other vegetation to create a uniform running surface, free of obstacles.

Table 1 Summary of stand and site conditions in the compartments

Stand parameters	Compartment M6	Compartment M7a	Compartment M7b
Area, ha	7.5	10.7	9.1
Age, years	37	37	37
Stand density, stem ha^{-1}	425	400	400
Average tree volume, m^3	0.87	0.99	0.99
Volume/ha	370 m^3 ha^{-1}	396 m^3 ha^{-1}	
Ground condition	Good in dry state Moderate in moist state Poor in wet state	Good in dry state Moderate in moist state Poor in wet state	Good in dry state Moderate in moist state Poor in wet state
Ground roughness	Slightly uneven	Slightly uneven	Slightly uneven
Slope condition	Gentle slope –10%	Gentle slope –10%	Gentle slope +10%

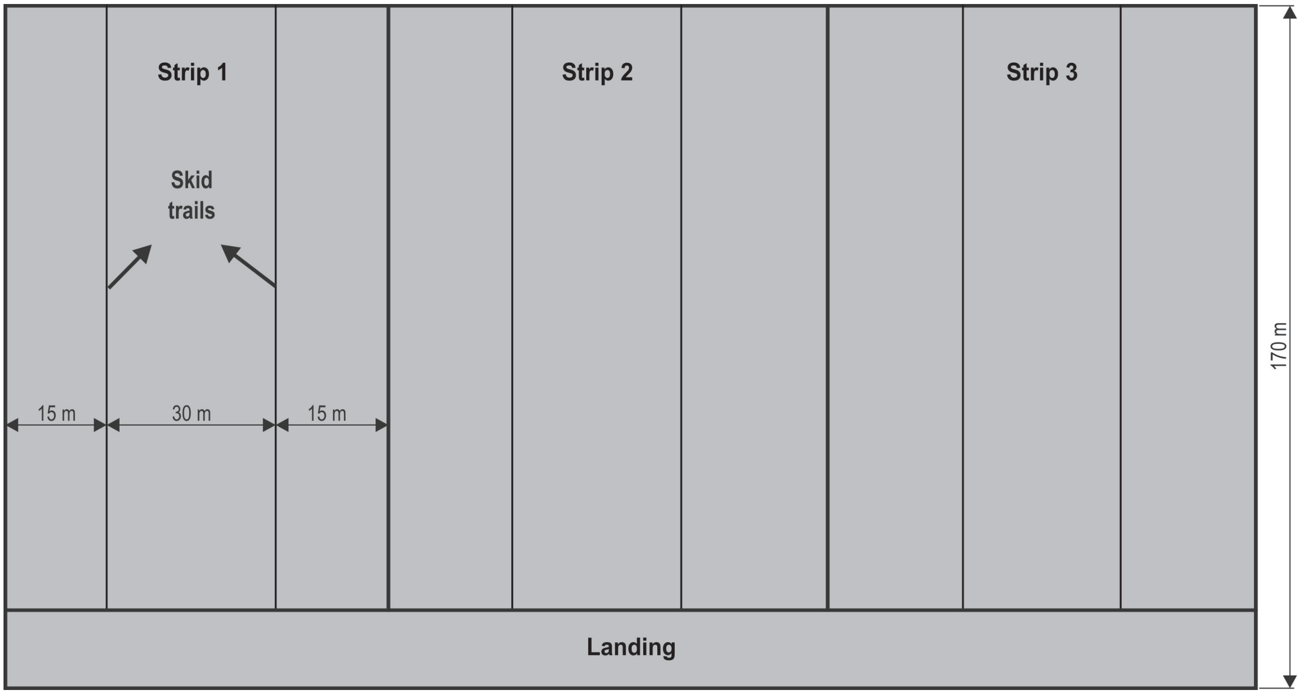

Fig. 3 Graphical representation of the harvesting plan within one compartment

Slash material was left on the surface of skid trails to improve ground stability, ensure suitable traction and limit potential damage to the soil. Roadside landings were located on the lower side of the three compartments to utilise gravity assisted skidding.

The operations commenced sequentially from strip 1 to 2 and finally to strip 3 in each of the three compartments. For each strip, extraction to the landing began only after the entire strip had been felled. Directional felling facilitated the tree-length extraction phase (Bromley 1969, Conway 1979, Spiers 1986, Andersson and Young 1998, MacDonald 1999). The skidder was confined to the pre-marked skid trails by winching the tree-lengths from both sides of the skid trail to the skid trail before returning to the roadside landing. Each of the two predetermined skid trails in each strip was randomly allocated either a mainline or tagline winching system: i.e., each system being applied in one of the skid trails in each strip. The mainline system was comprised of two sets of six choker chains (total 12). The two sets of choker chains facilitated pre-choking of tree-lengths infield, while the skidder was hauling the previous load to the landing. The tagline system was comprised of three taglines each having four choker chains (a total of 12 choker chains). Man-power requirements remained the same for both the mainline and tagline systems in the study and consist of two chocker-setters and one dechoker person at roadside landing. Generally, this is the arrangement of manpower in cable skidder operations country wide and the number of chocker setters will only increase if slope increases above 25 to 30% when up-hill pull by the crew of the wire rope is required (Ackerman et al. 2014). In this case, the number of choker-setters will increase from two to three.

In each skid trail, 20 work cycles were studied. This was determined from a pilot study on the skidder daily average work routine per shift using Eq. 1, George (1992).

$$\sigma p = \sqrt{\frac{PQ}{N}} \tag{1}$$

Where:

- Σp 5% standard error of proportion (the confidence level is 95%)
- P 14.5% non-work time
- Q 85.3% work time
- N number of cycles per skid trail

Individual work elements, comprising a work cycle, were identified in Table 2. The time consumption of each element was recorded. Load size (m^3) was derived from pre-determined tree-length volumes multiplied by the number of tree-lengths extracted per load. The GNSS tracking data was extracted from the GPS device at the end of the work shift and each cycle

Table 2 Elements comprising a work cycle and their break points

Work elements	Work element defined
Travel unloaded	From when the skidder starts to travel back infield at the landing to when the skidder operator releases the winch break to drop the chokers to the ground at the stump site
Choking	From when the skidder operator releases the winch break to drop the chain chokers to the ground to when it starts to move after its complete load has been winched
Travel loaded	From when the loaded skidder starts to move towards the landing to when it drops the load at the landing surface (once the winch has been released)
De-choking	From when the load makes contact with the landing surface to when the skidder starts to travel back infield

data matched to its respective time study data using real time recordings. The costs of the skidder and material (mainlines and chain chokers) were calculated using the South African Harvesting and Transport Systems and Costing Model (Hogg et al. 2009). Costs were then converted from ZAR to USD using an exchange rate of 0.073.

The data was analysed using Statistica Version 8. The Shapiro-Wilk test was used to test the normality distribution of residuals at 95% level of significance. The residuals were not normally distributed, and were then subjected to log, square root and exponential transformation in an attempt to normalise them. These transformation attempts were unsuccessful and the original data was analysed by non-parametric techniques: i.e., Kruskal-Wallis test and Bootstrapping. The Kruskal-Wallis test is used to compare three or more samples and is applicable in situations where the assumptions of ANOVA are violated (Siegel and Castellan 1988). When data are not normally distributed and transformation of the data is unsuccessful, non-parametric bootstrap multiple comparison tests are often used for statistical inference; H^0: $P(X<Y) = P(X>Y)$ against H^0 $P(X<Y) \neq P(X>Y)$ at $\alpha = 0.05$ (Reiczigelet al. 2005).

The bootstrap methods replace inaccurate approximations to biases, variances and other measures of uncertainty and have proved to work better than traditional methods in solving non-parametric problems (Davison and Hinkley 1997). Kruskal-Wallis test was used to test the differences between groups, specifically the differences between the compartments

Table 3 Comparison of cycle elements between tagline and mainline systems

	Mainline 6 choker chains	Tagline 4 choker chains	Statistical comparison	
			F	Sig
Choking time, min	3.47	2.13	118.445	0.0001***
Dechoking time, min	2.05	1.24	94.860	0.0001***
Travel empty time, min	0.95	0.78	0.959	0.328^{ns}
Travel loaded time, min	1.50	0.78	21.727	0.0001***
Travel empty distance, m	77.23	70.26	1.166	0.281^{ns}
Travel loaded distance, m	66.05	61.76	2.321	0.128^{ns}
Travel empty speed, ms^{-1}	1.35	1.50	3.614	0.060^{ns}
Travel loaded speed, m ms^{-1}	0.73	1.32	15.714	0.0001***
Load per cycle, m^3	4.51	3.46	86.791	0.0001***
Cycle time, min	7.97	4.93	105.485	0.0001***

*** – very highly significant
ns – not significant)

(M6, M7a and M7b) in terms of tree sizes and stocking (m^3 ha^{-1}). Bootstrap test was used to determine significant differences in cycle elements between the two systems.

3. Results of the study

The three compartments were adjacent and their stand and site conditions were homogeneous. There was no significant difference in tree size (P=0.89) or stand density (P=0.99) in the three compartments. The compartments did not, therefore, differ in terms of stems per ha or wood volume per ha. Similarities in stand and site conditions in all three compartments (Table 1) permit the pooling of data from the three compartments to analyse the differences between tagline and mainline systems against the independent variables. The statistical comparisons of productive work cycle elements for the mainline and tagline systems are presented in Table 3. The costs of using the mainline and tagline systems are presented in Table 4.

To account for the difference in the number of choker chains between the main and tagline, the cycle element times for travel empty and loaded, and load size of the mainline system were used to recalculate the productivity and cost for a tagline system using three sets of six chokers (Table 5). The cost per PMH of the skidder equipped with the tagline system increased slightly due to the additional six chokers in the system. To account for the larger load size with six tagline chokers, the loaded travel speed of the mainline system with six chokers was used.

Table 4 Machine productivity and costs when using mainline (2 sets of 6 choker chains) and tagline systems (3 sets of 4 choker chains)

System	Productivity m^3 PMH^{-1}	Cost US$ m^{-3}	Cost US$ PMH^{-1}
Mainline system	34.0	1.50	50.77
Tagline system	42.1	1.21	51.08

Table 5 Machine productivity and costs when using mainline and tagline systems with 6 choker chains per load

System	Productivity m^3 PMH^{-1}	Cost US$ m^{-3}	Cost US$ PMH^{-1}
Mainline system	34.0	1.50	50.77
Tagline system	46.5	1.10	51.12

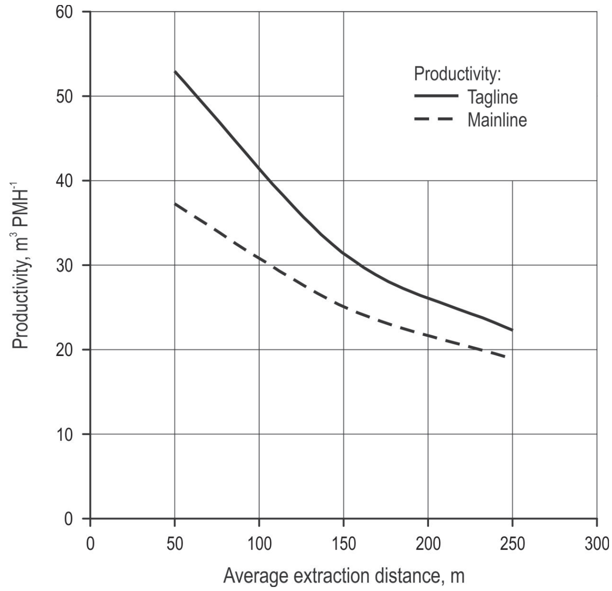

Fig. 4 Mainline and tagline cable skidding productivities modelled over 50 m, 150 m and 250 m average extraction distances

Based on the mean travel speeds, choking times, dechoking times and load sizes (Table 3), productivity of each system was modelled (Fig. 4) over three average extraction distances (50 m, 150 m and 250 m).

4. Discussion

The objective of the study was to compare productivity (m^3 PMH^{-1}) and cost (US$ m^{-3}) of mainline and tagline systems used in softwood sawlog tree-length extraction operations. In this study, the tagline system was introduced on a trial basis. The mainline system, contrarily, was already in use. Results show that productivity of the tagline system using four choker chains per load (42 m^3 PMH^{-1}) exceeds that of the mainline system (34 m^3 PMH^{-1}), even though there was a significant difference in load size extracted per cycle in the two systems: i.e., six chokers as opposed to four chokers for the main and tagline systems, respectively.

However, taglines are not commonly used in South Africa. One reason may be that practitioners are not aware of the potential benefits of increased productivity and reduced costs associated with the correct use of tagline systems (MacDonald 1999), particularly in smaller dimension timber, where it becomes difficult to attain optimal load sizes with more traditional choking systems (De La Borde 1992). Other reasons may be the increased degree of complexity and supervision required. However, the applicability of taglines goes beyond that of only smaller dimension timber, as demonstrated in this study. And although the study was conducted with unequal numbers of chokers between the mainline and tagline systems, there was a significant improvement with the use of the tagline system. However, with the simulation of equal numbers of chokers, a further improvement of productivity of 4.4 m^3 PMH^{-1} was achieved (Table 5).

The main differences between mainline and tagline systems occur during the terminal (choking and dechoking) phases of timber extraction (de Wet 2000, Lusso 2003), as demonstrated in Table 5. Taglines allow choking to take place prior to the return of the skidder to the compartment, while at the landing, where the entire tagline is removed for the dechoking process, the skidder can return to the stump site without delays. Pre-choking as well as quick attachment and release of taglines results in shorter cycle times compared to the mainline system. Choking and dechoking operations are prolonged using the mainline system. Shorter cycle times in taglines increases machine utilization, resulting in more cycles per PMH compared to the mainline system (Table 5) as Bromley (1969), APA (1988), De La Borde (1992) and MacDonald (1999) have shown.

The basic objective in industrial forest harvesting operations is to maximize productivity while minimizing costs (FAO 1998). Tagline system hardware is more expensive than mainline systems. The difference in costs between the two systems is related to the extra costs incurred in acquiring the taglines (a set of three taglines). In this study, the difference was US$ 2274.32 as opposed to US$ 1503.87 for a simulated mainline system comprising the winch line cable and two sets of six choker chains. The high costs of implementing the tagline systems are however offset by improved productivity. The unit production cost of operating the skidder using the tagline system (US$ 1.10 m^{-3}) was 26% less than the cost of operating the skidder using the mainline system (US$ 1.50 m^{-3}), making tagline systems more cost efficient.

It is interesting to note that the tagline productivity remains greater than that of mainline even over extraction distances of up to 250 m, but the difference between the two curves, however, diminishes with increasing distance (Fig. 4). This is due to the longer extraction distances off-setting terminal times. It is unfeasible to see where they equal each other as skidders operate best in the range of about 100 to 150 meters maximum extraction distance (MacDonald 1999).

5. Conclusions

Tagline system is more productive than the mainline system due to its shorter choking and dechoking times. Shorter terminal times result in shorter cycle times, which directly result in higher productivity of the tagline system. The higher cost of using the tagline system is offset by the high productivity resulting from the system. The tagline system is, therefore, more productive (46 m^3 PMH^{-1}) and cost efficient (US$ 1.10 m^{-3}) compared to the mainline system (34 m^3 PMH^{-1} and (US$ 1.50 m^{-3}) when using a cable skidder in semi-mechanised tree-length harvesting operations. Tagline systems are, however, more complex in use and require more operational awareness to maintain improved efficiencies. The results of this study will hopefully encourage the use of the more efficient choking systems within pine sawtimber tree-length extraction operations in South Africa.

6. References

Ackerman, P., Pulkki, R., Gleasure, E., 2014: Modelling of wander ratios, travel speeds and productivity of cable and grapple skidders in softwood sawtimber operations in South Africa. Southern Forests 76(2): 101–110.

Andersson, B., Young, G., 1998: Harvesting coastal second-growth forests: summary of harvesting systems performance. FERIC Technical report 120 p.

APA, 1988: Timber harvesting, Fourth edition, American Pulp Wood Association. The Interstate Printers & Publishers, Illinois.

Behjou, F.K., Majnounjan, B., Namjranian, M., Dvořák, J., 2008: Time study and skidding capacity of the wheeled skidder Timberjack 450C in Caspian forests. Journal of Forest Science 54(4): 183–188.

Bromley, W.S., 1969: Pulpwood production, 2nd edition, Interstate Printers & Publishers, Illinois.

Conway, S., 1979: Timber Cutting practices, Miller Freeman Inc., San Francisco.

Davison, A.C., Hinkley, D.V., 1997: Bootstrap methods and their application. Cambridge University Press, New York.

De La Borde, R.M., 1992: Timber harvesting manual, Institute for Commercial Forestry Research, South Africa.

De Wet, P., 2000: Ground based extraction. In: South African Forestry Handbook (Owen, D.L., ed.), South African Institute of Forestry, South Africa, 316–322.

Erasmus, D., 1994: National terrain classification systems for forestry. Institute for Commercial Forestry Research, Bulletin Series 684/3/3, South Africa.

FAO, 1998: Conventional versus environmentally sound harvesting: impacts on non-coniferous tropical veneer log and saw log supplies. Unasylva 49(193): 23–30.

FESA, 1999: Guidelines for forest engineering practices in South Africa,Forest Engineering South Africa, South Africa.

George, T. 1992: Harvesting forest products, Stobart Davies ltd, Greece.

Hogg, G.A., Krieg, B., Ackerman, P.A., Längin, D.W., 2010: Harvesting system and equipment costing. In: Ground based harvesting handbook (Längin, D.W. & Ackerman P.A., ed.), FESA Publication, South Africa, 88 p.

Reiczigel, J., Zakariás, I., Rózsa, L., 2005: A bootstrap test of stochastic equality of two populations.The American Statistician 59(2): 156–161.

Kluender, R., Lortz, D., McCoy, W., Stokes, B., Klepac, J., 1997: Productivity of rubber – tired skidders in southern pine forests. USDA Forest Products Journal 47(11–12): 53–58.

Lusso, C., 2003: Ground based extraction within forest harvesting systems. MSc thesis, University of Natal, Pietermaritzburg, South Africa.

MacDonald, A.J., 1999: Harvesting systems and equipment in British Columbia. FERIC Hand book No. HB – 12, British Columbia.

Reutebuch, S.E., Fridley, J.L., Robinson, L.R., 1999: Integrating real-time forestry machine activity with GPS positional data. ASAE Technical Paper No. 99-5037.

Robert, H.D., 2002: The feasibility of using GPS technology for continuous time studies of rubber-tired grapple skidders. MSc Thesis, Louisiana State University, USA.

Ronald, C., Mauricio, M., Oscar, M., 2006: Evaluation of Forestry Machinery Performance in Harvesting Operations using GPS Technology. In: Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa, 5–10 March.

Rummer, B., 2002: Forest operations technology. In: Southern Forest Resource Assessment General Technical Report SRS-53. USDA-Forest Service Southern Research Station, Asheville, USA, 341–353.

Siegel, S., Castellan, N.J., 1988: Nonparametric statistics for the behavioral sciences, McGraw-Hill International, Singapore.

Spiers, J.J.K., 1986: Logging operations guidelines, LIRO, Wellington.

Spruce, M.D., Taylor, S.E., Wilhoit, J.H., Stokes, B.J., 1993: Using GPS to track forest machines. In: International Winter Meeting sponsored by the American Society of Agricultural Engineers. ASAE, Chicago, Illinois, December 14–17.

Stenzel, G., Kenneth, J.P., Thomas, A.W., 1985: Logging and pulpwood production, John Wiley & Sons, New York.

Veal, M.W., Taylor, S.E., McDonald, T.P., McLemore, D.K., Dunn, M.R., 2000: Accuracy of tracking forest machines with GPS. In: ASAE Annual International Meeting. American Society of Agricultural Engineers, Wisconsin, USA, 9–12 July.

Veal, M.W., Taylor, S.E., McDonald, T.P., Tackett, D.K., Dunn, M.R., 2001: Accuracy of tracking forest machines with GPS. Transaction of ASAE: Chicago, Illinois.

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